SUMMARY

- Enclosed Laminar Flames (ELF) is a microgravity combustion investigation.
- The primary objective of ELF is to understand the mechanisms controlling the stability and extinction of jet diffusion flames.
- ELF is part of the fourth United States Microgravity Payload (USMP–4), which is a series of experiments that will fly on the STS–87 mission of the Space Shuttle *Columbia*, scheduled for late 1997.
- ELF is an astronaut-operated investigation, that will be conducted in the Middeck Glovebox (MGBX) facility.

MICROGRAVITY

Microgravity is a term used to describe a condition where the apparent weight of an object is much less than its true weight (on Earth). This condition is achieved on orbiting spacecraft, such as the Shuttle, because of their free-fall orbit, and not because of their distance from the Earth. Free fall occurs whenever the only significant force acting on an object is gravity. Once the Space Shuttle is in orbit (about 8 minutes after launch), the engines are shut off and it is simply coasting. It is freely falling toward the Earth, but it is moving at such a high velocity that it does not strike the Earth. Under these free-fall conditions, the Space Shuttle and its contents experience apparent weightlessness.

COMBUSTION IN MICROGRAVITY

Combustion is strongly effected by the buoyant convection caused by gravity. On Earth, buoyancy causes hot (less dense) combustion gases to rise in the cold (more dense) air. The hot combustion gases are still present in a microgravity environment, but there is no buoyant acceleration. Therefore the microgravity motion of the gases is dependent on any forced flows and weaker mechanisms such as diffusion. For example, in microgravity, a candle flame assumes a hemispherical shape because there is no preferred direction of movement for the combustion gases.

INTRODUCTION

Enclosed diffusion flames are commonly found in practical combustion systems, such as the power-plant combustor, gas turbine combustor, and jet engine after-burner. In these systems, the fuel is injected into a duct with a co-flowing or cross-flowing air stream. The diffusion flame is located at the surface where the fuel jet and oxygen meet, react, and consume each other. In combustors, this flame is anchored at the fuel jet inlet (i.e., nozzle) unless adverse conditions cause the flame to become unstable and lift off or blow out.

The stability of enclosed jet diffusion flames will be investigated in the Enclosed Laminar Flames (ELF) investigation that will be conducted in the Middeck Glovebox (MGBX) facility on the STS–87 Space Shuttle mission, scheduled for late 1997. The investigation was jointly proposed by scientists of The University of Iowa and the NASA Lewis Research Center.

SCIENCE OVERVIEW

Flame stability is strongly dependent on the fuel jet velocity. When the fuel jet velocity is sufficiently low, the diffusion flame anchors at the burner rim. When the fuel jet velocity is increased, the flame base gradually moves downstream. However, when the fuel jet velocity increases beyond a critical value, the flame base abruptly jumps downstream as shown in Figure 1. When this "jump" occurs, the flame is said to have reached its lift-off condition and the critical fuel jet velocity is called the lift-off velocity. While lifted, the flame is not attached to the burner and it appears to float in mid-air. Flow conditions are such that the flame cannot be maintained at the burner rim despite the presence of both fuel and oxygen. When the fuel-jet velocity is further increased, the flame will eventually extinguish at its blow-out condition. In contrast, if the fuel jet velocity of a lifted flame is reduced, the flame base moves upstream and eventually returns to anchor at the burner rim. The fuel jet velocity at reattachment is different from that at lift off, illustrating the hysteresis effect present in flame stability.

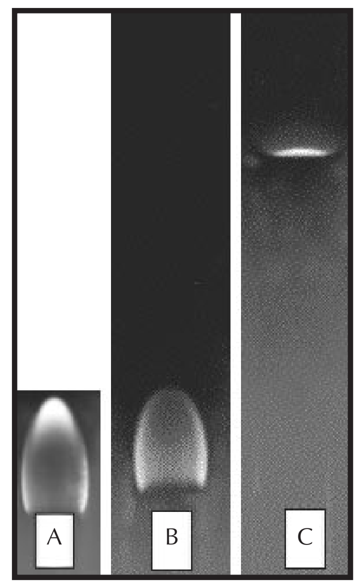

Figure 1.–Lift off on Earth.

The air flow around the fuel jet can also significantly alter the lift off, reattachment and blow out of the jet diffusion flame. The effects of the air flow on the diffusion flame stability in normal gravity, however, are complicated by the presence of buoyant convection. Buoyant convection is sufficiently strong in normal-gravity flames that it can dominate the flowfield. In normal-gravity testing, it is very difficult to delineate the effects of the forced air flow from those of the buoyancy-induced flow. However, a comparison of normal-gravity and microgravity flames will clearly indicate the influence of forced and buoyant flows on the flame stability.

OBJECTIVES

The primary objective of the ELF investigation is to determine the mechanisms controlling the stability and extinction of jet diffusion flames. Specifically, the study will focus on the effect of buoyancy on the flame characteristics and velocities at the lift off, reattachment, and blow out of the flame. The analysis and interpretation of the results is simplified in ELF by limiting the study to laminar, axisymmetric (2D), gas-jet diffusion flames in a co-flow duct. Although flames in practical combustors are generally turbulent, they are typically laminar at the base. The resulting data will be used to verify theoretical predictions of the stability of ducted laminar jet diffusion flame.

The secondary objective of ELF is to verify the zero-gravity Burke-Schumann model and the gravity-dependent Hegde-Bahadori extension. Experimental validation of the 1928 Burke-Schumann diffusion flame analysis is of particular interest, because of the fundamental and historical role of the analysis.

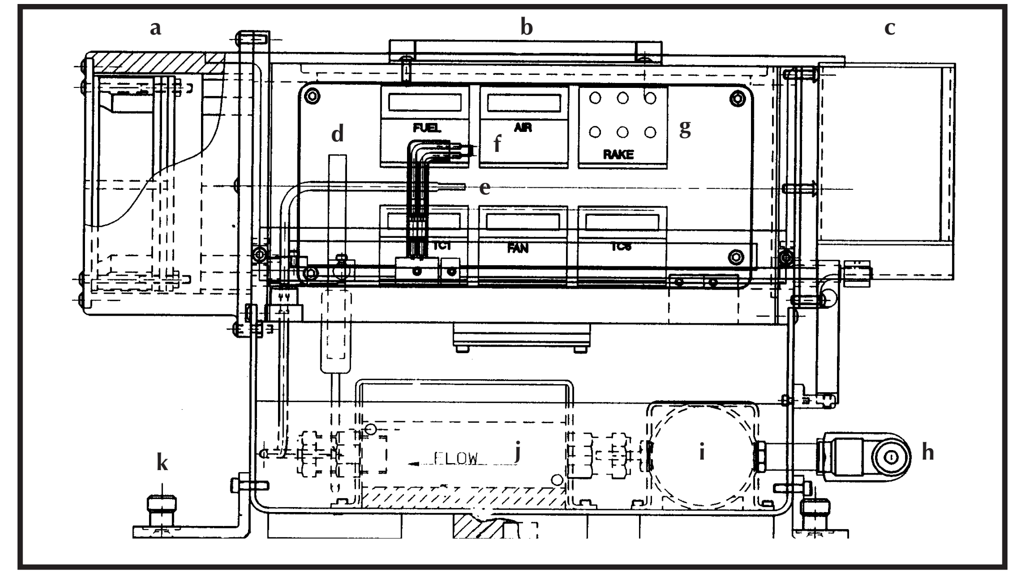

Figure 2.–Front-view schematic of the ELF module, with the following parts identified: (a) fan housing, (b) test section, (c) exhaust guard, (d) hot-element anemometer, (e) nozzle, (f) exchangeable hot-wire ignitor, (g) 6 data displays, (h) quick-connect fuel inlet, (i) pressure regulator, (j) mass flow controller, and (k) bolt-down fastener.

ELF HARDWARE

The ELF hardware consists of an experiment module and a parts box containing a control box, camera shroud, 3 electrical cables, 4 fuel bottle assemblies, ignitors, and a few miscellaneous parts. Two 2 additional fuel bottle assemblies will be stowed separately. The hardware was designed by engineers of Aerospace Design & Fabrication, Inc. (Brook Park, Ohio) and the NASA Lewis Research Center.

The experiment module shown in Figure 2, is a miniature, fan-driven wind tunnel, equipped with a gas supply system. The module is 33x18x18 cm and just fits within the glovebox facility. A 1.5-mm diameter nozzle is located on the duct's flow axis. The cross section of the duct is nominally a 76-mm square with rounded corners. The air velocity can be varied from 10 cm/s to over 50 cm/s, and is measured with a hot-element anemometer. The fuel flow is adjusted with a fixed pressure regulator and a mass flow controller. The fuel flow can be set as high as 3 std. cc/s, which corresponds to a nozzle exit velocity of up to 170 cm/s. The module is equipped for a replaceable hot-wire ignitor, which is manually rotated to the nozzle exit. The nozzle is instrumented with a surface thermocouple, and another thermocouple at the duct outlet is used to indicate extinction of the flame. The duct is also equipped with an astronaut-positionable temperature rake (not shown), which is instrumented with 5 type-R thermocouples and 26 silicon carbide fibers. When exposed to the flame, the fibers thermally radiate giving a qualitative indication of the near-flame temperature profile. The rake can be positioned at 6 discrete radial positions (at 0, 2, 4, 7, 10, or 15 mm from the axis). The fuel flow, fan voltage, air velocity, rake position, and 2 temperatures are displayed for astronaut viewing on the module.

The control box is mounted outside of the glovebox and provides manual controls for the fuel flow and fan velocity, an ignitor switch, and a flame-out indicator.

Each fuel bottle assembly consists of a 75-cc bottle, equipped with a hand valve and a quick-connect for attachment to the ELF module. Each bottle will be filled to 350 psig with a 50/50 mixture (volume basis) of methane and nitrogen. Multiple bottles are used to limit the amount of fuel that is placed within the glovebox at one time. Diluted methane is being used because (a) the fuel and its combustion products are not toxic, (b) the combustion chemistry is well established, and (c) there is minimal soot production so the flame is nearly all blue.

FLAME–OUT ACTIVITY

For safety reasons, this experiment should NOT be performed without adult supervision!

Background

Flame stability can be studied with a simple candle flame. The existence of the flame is dependent on its access to sufficient fuel, oxygen, and heat. Inspection of the flame will reveal that there is a gap between the flame and the candle.This is due to heat loss to the wax causing local extinction of the flame. Blowing on the flame will cause it to change shape, and partially or completely extinguish. In this case, the extinction is due to loss of both heat and fuel (vaporized paraffin). A candle flame will not lift off as in ELF because the flame must be near the candle to vaporize the wax. A dropped candle will extinguish due to the strong buoyant convection caused by impact.

Materials

- candles and matches
- 2-liter pop bottle (with top cut off and short candle mounted in base)
- fire extinguisher (ready to use)
- video camera (optional)

Procedure

It is recommended that this activity be performed over aluminum foil for safety and easy clean up.

With partner(s), observe the appearence of a candle flame when:
(1) the air is steady (w/o drafts),
(2) it is weakly blown on,
(3) it is blown on more forcefully,
(4) it is blown on with a forceful puff,
(5) right before it goes out,
(6) when it is dropped onto the floor in the pop bottle (see above)

Discussion Questions

(1) What are the three things needed for a fire to burn? (2) Can a flame be partially extinguished? (3) Why is there a gap between the flame and the candle? (4) What provides the heat for a flame after the ignition source is removed? (5) How is the flame effected by: (a) weak blowing? (b) increased blowing? (c) a strong puff? (6) What was the shape of the flame just before it blew out? (7) Why does a candle flame exinguish when you blow on it? drop it? (8) Why is it difficult to ignite a log with a match?

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WWW Sites

ELF Investigation
http://zeta.lerc.nasa.gov/expr/elf.htm

USMP-4 (set of experiments)
http://liftoff.msfc.nasa.gov/shuttle/usmp4/

STS-87 Mission
http://www.ksc.nasa.gov/shuttle/missions/sts-87/mission-sts-87.html

Space Shuttle
http://shuttle.nasa.gov/

NASA
http://www.nasa.gov/

Lewis Research Center
http://www.lerc.nasa.gov/

Microgravity Science Division
http://zeta.lerc.nasa.gov/

Related Educational Sites
http://zeta.lerc.nasa.gov/new/school.htm
http://quest.arc.nasa.gov/shuttle/
http://liftoff.msfc.nasa.gov/
http://spacelink.nasa.gov/

GLOVEBOX FACILITY

The ELF investigation will be conducted within the Middeck Glovebox (MGBX) facility. This facility is used to conduct a variety of small-scale, astronaut-operated investigations, designed to provide valuable scientific data with a minimum cost and schedule. Through use of gloveports and removable doors, the facility provides containment of potentially hazardous materials. It also provides air circulation and filtration, electrical power, lighting, and video photography and recording. The video system also allows for data recording onto the audio track of the video tapes. ELF is one of three MGBX investigations to fly on STS–87.

The Glovebox facility was developed by Bradford Engineering (Netherlands) and Teledyne Brown Engineering, under contract to the NASA Marshall Space Flight Center.

EXPERIMENT PROCEDURE

The ELF investigation can be conducted by a single astronaut. To prepare for ELF, the astronaut will remove the hardware from stowage and assemble it within the glovebox. Two color video cameras will be set up to record the flame and the ELF module's data displays. The astronaut will then follow a table of test parameters and procedures in operating the experiment. There are three major operational variables: the fuel flow, air velocity, and the position of the temperature rake. There are six different test scenarios described in the table below. Following the scenario procedure, the astronaut will ignite the flame and then make periodic incremental changes to the test parameter (e.g., air velocity for scenario A). At typical flow rates, each fuel bottle will provide about 20 minutes of burn time.

ELF Test Scenarios

Scenario	Fuel Flow	Air Velocity	Measurement Focus
A – Alpha	Fixed	Increasing	Conditions at lift off, reattachment, blow out
B – Bravo	Increasing	Fixed	Conditions at lift off, reattachment, blow out
C – Charlie	Decreasing	Fixed	Conditions at lift off and blow out
D – Delta	Fixed	Increasing	Temperature field
E – Echo	Increasing	Fixed	Temperature field
F – Foxtrot	Decreasing	Fixed	Temperature field

During operations, the investigators will monitor the progress of the investigation at the Payload Operations Control Center (POCC) at the NASA Marshall Space Flight Center. They will review the downlinked video from the front-door camera so they can recommend appropriate conditions for subsequent tests.

POSTFLIGHT ANALYSIS

Following the mission, an image processing workstation will be used to make detailed measurements from the recorded videotape. Character recognition software will be used to generate digital records of the data displayed and recorded on the videotape. Automated object-tracking software will be used to track the position of the flame base and tip as a function of time. The lift-off and reattachment limits will be determined by comparison of the flame-base position with the flow variable. These limits will be used to create a map of the flame stability as a function of the fuel flow and air velocity. The results from normal-gravity testing, performed in the flight hardware following the mission, will be used to generate a similar stability map. A direct comparison of the two stability maps will clearly indicate the influence of bouyant convection on the flame stability. Similar stability maps will be generated using results computed by direct numerical simulation. The experimental and theoretical stability maps will be compared to verify the accuracy of the current theoretical understanding. Similarily, the temperature data will be used to create maps of the temperature field around the flame, which will in turn be compared to the theoretical predictions to verify our understanding of the mechanisms causing flame instability.

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Enclosed Laminar Flames (ELF) Investigation

ELF hardware assembled for testing.

National Aeronautics and
Space Administration

Lewis Research Center
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Office of Life and Microgravity Science and Applications
Microgravity Research Division

Space Directorate
Microgravity Science Division